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The Interaction of Laser Driven Shock Waves with a Spherical Density Perturbation

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Strong shock waves produced by illumination of a CH target by laser produced x-rays were driven through a copper sphere. The motion and deformation of the sphere were measured using radiographs generated by backlighting the sphere with a large area backlighter. The sphere became non-spherical after the passage of the shock, having a complicated down-stream structure. This was an instability-induced structure that was predicted by calculations. The experiment is a convenient laboratory model of the complicated interactions occurring in much larger systems such as in astrophysics in the interaction of shocks formed in the interstellar medium with various types of clouds. In particular, the experiment is a useful tool for checking the computational ability of the new generation ASCI computers, as it requires three-dimensional modeling.

A schematic description of the experiment is shown in Figure 1. The diagram is not to scale, and the area of the target package is greatly expanded. Eight Nova laser[1] beams were focussed into a cylindrical gold hohlraum producing a broad spectrum of x rays which ablated the surface of the brominated plastic. The relatively planar shock wave produced by the ablation traveled down the cylinder, passing the copper sphere. Two additional laser beams impinged on a titanium backlight target producing x-rays from transitions from n=1 to n=2 levels in He-like Ti (~4.7 keV) which passed through the cylinder perpendicular to its axis and were detected by the imaging camera. Differences in optical density to the backlight x-rays formed a shadowgram which allowed positional information on the shock front and the sphere to be obtained. The copper sphere was opaque to the backlighter and had a nominal diameter of 100 μm.

Eight of the ten Nova laser beams were used to heat the hohlraum and the two remaining beams were defocussed onto the backlight target to produce a radiation source which was oval shaped with a diameter of 800μm. Since the objective was to measure the positions of both the shock front and the sphere as a function of time, the delays of the backlight beams were varied from 20 to 70 ns after the beginning of the laser pulse. The camera was opened 0.5 ns after the start of the backlight beams.

The heating laser pulse width was one ns in length, and the backlight pulse widths were typically 2 ns. The backlit pulses were typically staggered with about 6 ns between the two pulses. The camera used here used a gated microchannel plate[2] having four strips, with a variable time delay between the strips.

Figure 2 shows an example of the raw film data for one shot which shows very clearly the position of the shock front and the early deformation of the sphere. With uniform drive from the hohlraum, one would expect to have a perfectly flat shock front. As can be seen, the front is relatively flat, but does begin to deviate from a flat shock. It is important in examining these images to remember that we only have a two dimensional image of the transmission of the backlight x-rays, and structures in the third dimension can only be inferred. The figures clearly show the shock just as it reaches the sphere and after the shock has passed through the sphere. Note the change in shape after the shock has passed.

The grid seen in each of the images in Figure 2 is a spatial fiducial made from a gold grid mesh having a 60 μm wire to wire spacing. The exact locations of the grids were measured before each shot allowing the magnification of the camera and the positions of the sphere and shock to be determined from the radiograph.

It was necessary to make a correction for parallax to the positions measured on the film, as there were significantly varying angles between the axis of the camera and the line between the strips and the target. The data were extracted from the film after digitizing and analyzing the digitized data using a two dimensional image analysis program[3].

Figure 3 shows a series of sphere-shock shadowgrams obtained from times from 20 to 26.5 ns after the laser pulse and show the early time crushing of the sphere.

Figure 4 shows some later time sphere images together with two-dimensional and three-dimensional calculations of the shock-sphere interaction. The comparisons are made at ~43 and ~53 ns. This corresponds to 3.0 and 4.2 crushing times (t_{cc}). A crushing time is defined as the time required for the shock to traverse the sphere and is given by

$$t_{cc} = (\rho_{cll}/\rho_{ISM})^{1/2}(a_{cl}/v_{shock})$$

where ρ_{cll} is the copper density, ρ_{ISM} is the density of the plastic, a_{cl} is the sphere radius and v_{shock} is the shock velocity[4]. The crushing time in this experiment was about 8 ns.

2D CALE is an arbitrary Lagrange-Eulerian multifluid hydrodynamic code using realistic equation of state data. AMR is a single fluid adaptive mesh refinement calculation assuming an ideal gas equation of state. It is seen from the figure that the three dimensional code is required to show the voiding and complicated down-stream structure which is apparent in the experimental data.

Figure 5 gives the shock and sphere positions as a function of time after the beginning of the heating laser pulse. The shock positions were measured on a vertical line through the center of the sphere. This was done because there was some variation in the shock position in the lateral direction, probably due to non-uniformity in drive. The sphere position was that measured for the center of the spheres, even though in many cases later in time, the sphere was definitely not spherical.

Figures 6 and 7 show the change in shape of the sphere as a function of time. The sphere width and height are plotted as a function of time after the laser pulse, where the width is the length of the sphere perpendicular to the drive axis and the height is the length of the sphere in the drive direction.

This experiment has shown that three dimensional calculations seem to be necessary to describe major features observed in the experiment Any attempt to explain hydrodynamic behavior with similar instabilities must take into account these three dimensional effects.

References

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2. K. S. Budil et al, Rev. Sci. Instrum., 67, 485 (1997).

3. PDS Shrink, private communication D. W. Phillion.

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Figures

1. Schematic arrangement of experiment (not to scale) showing a cross-section through a cylindrical target used for the sphere experiment. The dimensions given on the target package are nominal and were varied from experiment to experiment.

2. This figure shows a set of shadowgrams for one shot. The horizontal change in film density is the shock front. The grid is a fiducial which allowed for calibration of the camera magnification. The times given are from the beginning of the heating laser pulse.

3. This figure shows a series of sphere-shock shadowgrams obtained from times from 20 to 20.5 ns after the laser pulse and show the early time crushing of the sphere.

4. This figure is a comparison of two sphere images with two-dimensional and three-dimensional calculations. The voiding and lower extension portions of the image seem to be only obtainable with the three dimensional calculation.

5. Results of the sphere experiment showing the position of the shock front and the position of the center of the sphere as a function of time after the beginning of the heating laser pulse. The zero of the ordinate is the position of the sphere before the beginning of the drive. The shock front was measured in a vertical line passing through the center of the sphere, as the shock fronts were not always parallel to the x-axis.

6. This plot gives the values of sphere width for the sphere as a function of time where the sphere width is the length of the sphere along the axis perpendicular to the drive.

7. This plot gives the values of sphere height as a function of time where the sphere height is the length of the sphere along the axis in the direction of the drive.

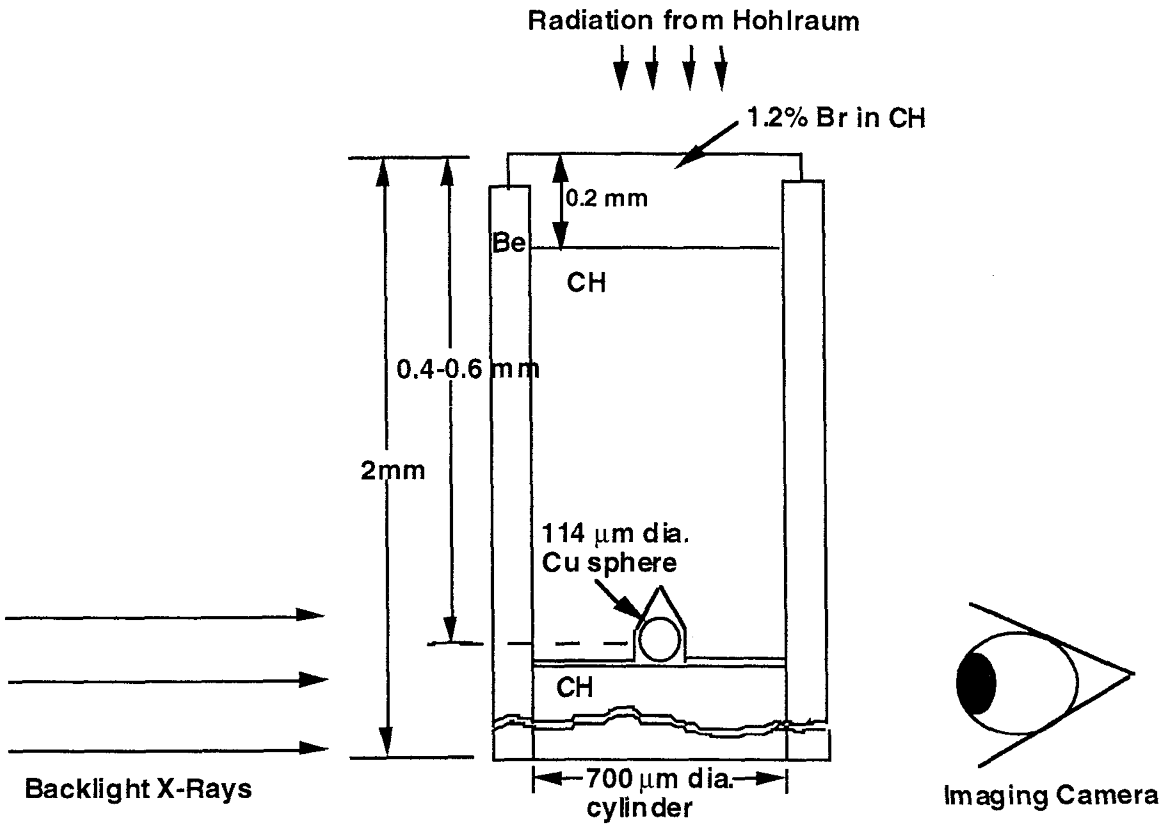
Radiation from Hohlraum
1.2% Br in CH
0.2 mm
Be
CH
0.4-0.6 mm
2mm
114 μm dia.
Cu sphere
CH
Backlight X-Rays
700 μm dia.
cylinder
Imaging Camera

Figure 1

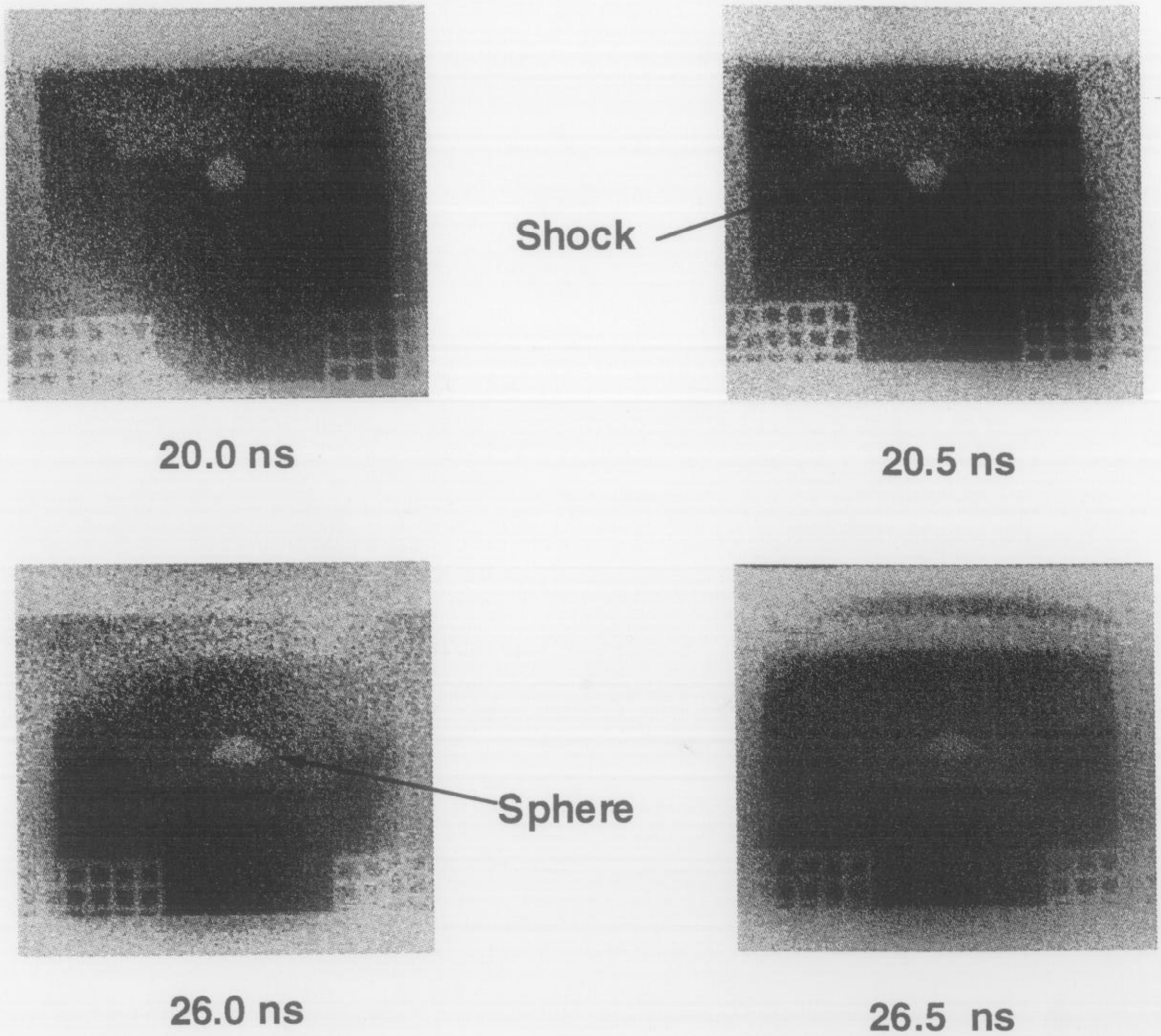

Figure 2

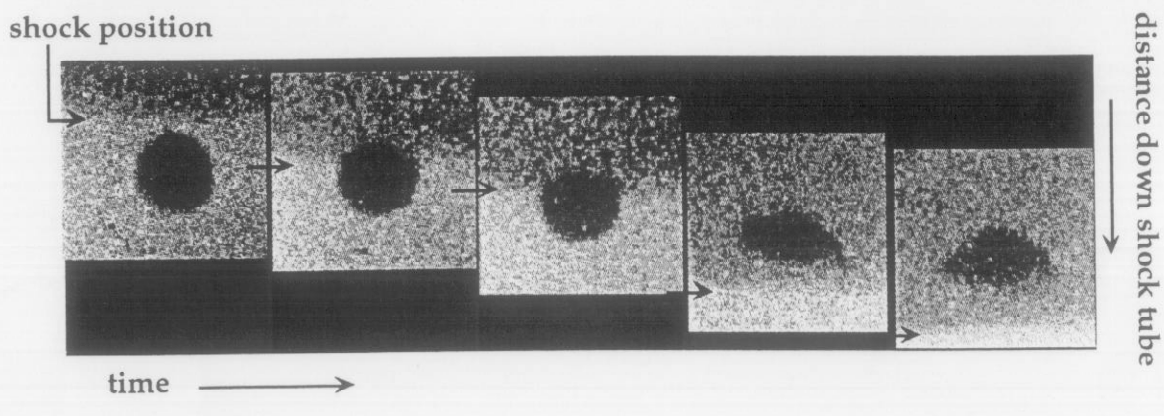

Figure 3

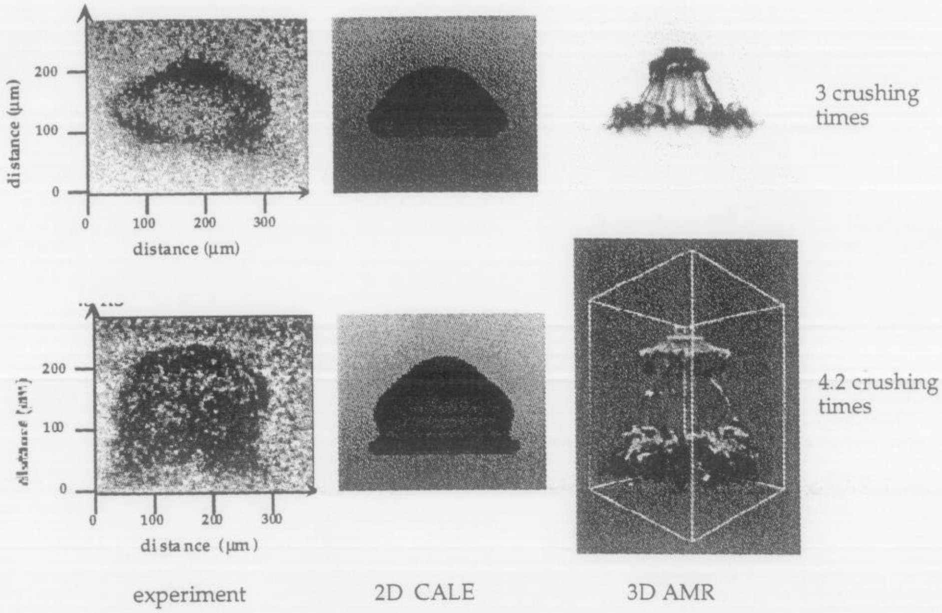

Figure 4

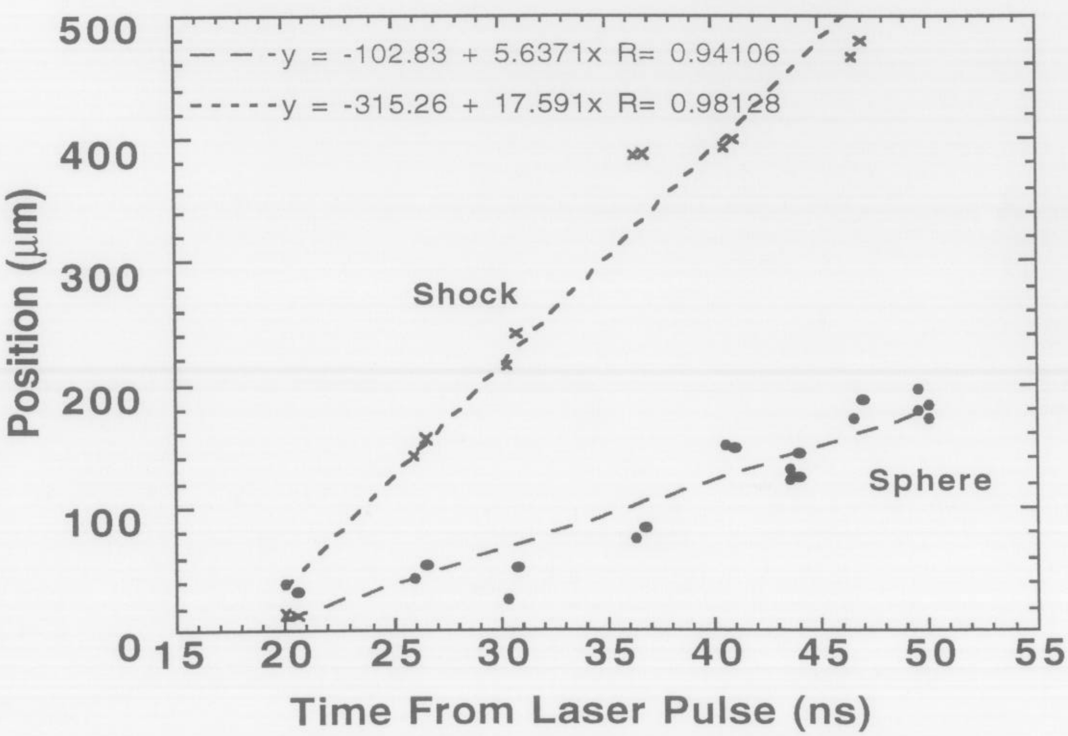

Figure 5

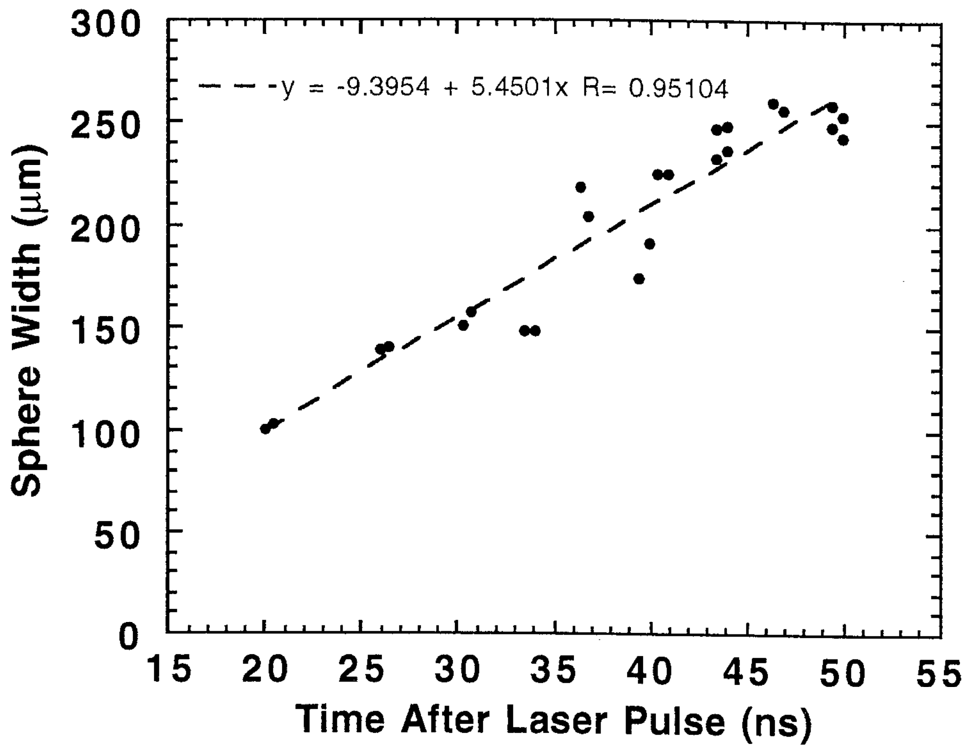

Figure 6

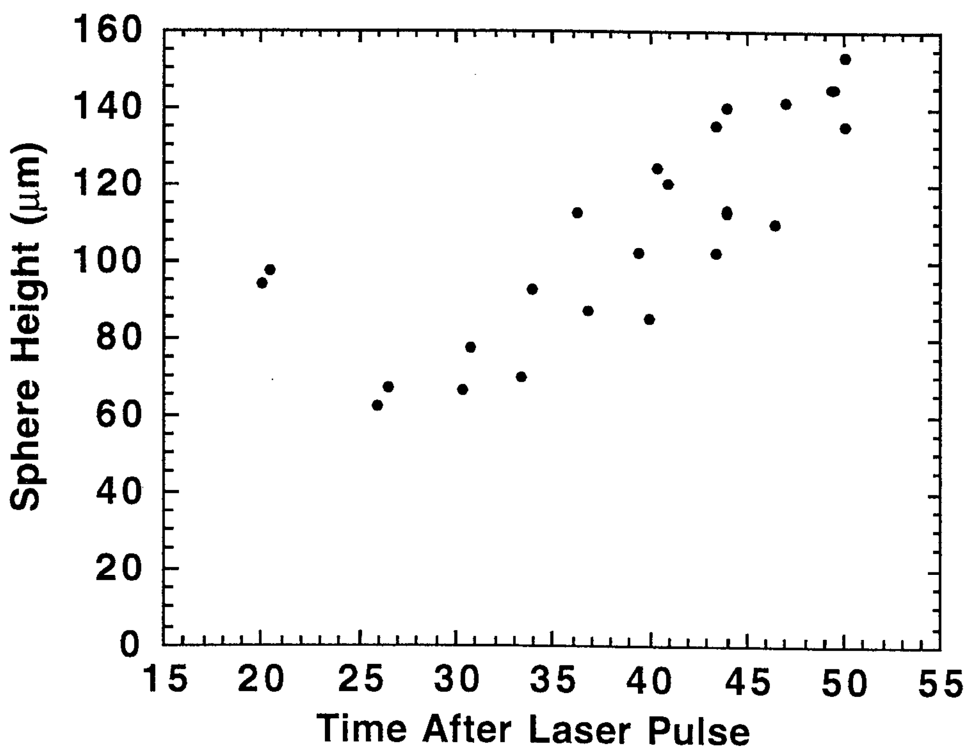

Figure 7